52% of the portfolio are the top 4 that have the most "X"s, address the most megatrends

GIP PROGRAMS

		Megatrends										
		I - Phys & Cyber Threats	II - Adv Tech (Solar/Battery)	III - Environmental Policy	IV - Weather	V - Grid Improvement Tech	VI - Concentrated Growth	VII - Customer Expectation	DEC-SC	DEP-SC	TOTAL	
PRO	Physical & Cyber Security	x	x			x		x	**37.9**	**17.1**	**55.0**	**SECOND**
Optimize	Self-Optimizing Grid	x	x	x	x	x	x	x	**65.6**	**31.0**	**96.6**	**FIRST**
	Integrated Volt/VAR Control	x	x	x	x	x	x	x	**43.6**	**2.0**	**45.6**	**THIRD**
	Harden &Resiliency [T]		x	x	x			x	23.8	7.4	31.2	
	Targeted Underground				x			x	19.7	7.8	27.5	
	Energy Storage		x	x	x		x	x	16.4	8.1	24.5	
	Transformer Retrofit [D]				x			x		23.0	23.0	
	Long Duration Interruptions				x			x	12.9	9.9	22.8	
	Transformer Bank Repl [T]		x	x				x	7.1	2.9	10.0	
	Oil Breaker Rpl [T/D]			x		x		x	6.1	1.4	7.5	
Modernize	Enterprise Communications	x	x	x	x	x	x	x	**25.3**	**15.7**	**41.0**	**FOURTH**
	Distribution Automation		x	x	x	x		x	19	6.5	25.5	
	System Intelligence [T]		x	x		x		x	16.7	5.1	21.8	
	Advanced Enterprise Systems		x	x		x		x	5.3	2.1	7.4	
	ISOP/ADP		x	x		x	x	x	4.8	1.4	6.2	
	DER Dispatch		x	x		x		x	2.9	1.0	3.9	
	Electic Transportation		x	x					2.2	1.0	3.2	
	Power Electronics		x	x		x		x	1.3	0.4	1.7	
											454.4	

	Under Business as Usual	With Grid Improvement Plan
Increased Costs	Gradual Yellow to Red  **2018-2020 (yellow)**: Service interruptions already lead to significant costs for customers, especially business interruptions (a 4-hour outage costs medium to large business almost $40K on average and even a momentary interruption costs over $12K) [Source: Lawrence Berkley National Laboratory 2015 Value of Service report]. Investments to relieve capacity constraints due to redevelopment in urban/suburban areas becoming increasingly expensive (land, double/triple circuit feeders, etc.). Increasing major event days (MEDs) also leading to large restoration costs (2018 alone, $540M is attributed to Florence in the Carolinas). [Source: DE data] **2021-2024 (worsening to red):** Outage trends get worse due to increased MEDs and aging infrastructure. Trend projects on average $150M/year in MED restoration costs by 2023. Increased outages continue to drive up costs incurred directly by customers, as well as affecting rates in future years. Cyber and physical attacks expected to mount as well (single sniper incident cost PG&E $15M in direct substation repair and impact of Ukraine type cyber incident in US estimated to be $246 billion-$1 trillion) [Source: see SC Megatrend I]. **2025-2027 (all red):** Trends above continue to increase, and distributed energy resources (DER) penetration reaches a level that additional costs are incurred to accommodate (e.g., SC PV growth projection 904 MW just over the next 5 years) [Source: SEIA SC factsheet] and electric vehicles (EVs) have seen a compound annual growth rate of 43% since 2011 [source: SC pre-read], increasing costs to accommodate charging infrastructure.	Gradual Yellow to Green  **2018-2020 (yellow)**: Targeted Undergrounding (TUG), Self-Optimizing Grid (SOG) and transmission and distribution (T&D) automation all put the infrastructure in place to reduce customer outages. IVVC also puts in place the means to reduce customer costs as well as integrate more DERs. The effects start to take place towards the end of the initial 3 to 4-year implementation. **2021-2024 (lime):** The reliability investments above start to pay dividends, decreasing customer costs by reducing outages and momentary interruptions, as well as by reducing outage and MED restoration costs. Customer energy savings start to accumulate as integrated volt/VAR control (IVVC) allows areas of the system to be run at lower voltages, saving energy, in accordance with benefits illustrated in the IVVC business case analysis (BCA). SOG, IVVC and Power Electronics also allow more cost effective and faster DER integration. [This is because many of the same capacity and automation investments that enable rapid power restorations and voltage control are the same technologies that are needed to manage DER-generated oversupply and power quality at the local circuit level.] **2025-2028 (all green):** Investments work together to improve reliability and enable DERs more efficiently. SOG alone (proposed 3-year SC scope) expected to produce $300M in customer benefit from reduced customer interruptions (outages and momentaries) over its lifetime. IVVC business case analysis illustrates the additional benefits produced by 2028.

Details

Service interruptions lead to costs for customers, especially business interruptions (an hour outage costs medium to large business almost $40K and even a momentary interruption costs over $12K). [Source: Lawrence Berkley National Laboratory 2015 Value of Service report]

MEDs – Major Event Days—reliability and cost drivers

- Trending upwards for past 10 years for the Carolinas. Trend shows 6 more MEDs/year in 2018 than 2008 (from trend of 13 to over 19).
- MEDs have increased 6% per year (trendline)
- MEDs are disruptive to reliability and expensive to respond to and address problems created.
- Each MED costs $millions, raising cost of service.
- National Weather Service has cited an 80% increase in the number of severe weather events impacting the U.S. from 2000 to 2016. [Source: DE data]

Storm Restoration Costs – increasing weather events drive higher costs

- Repair cost per MED increasing (approx. $2M in 2013 to over $8M in 2017. 2018 saw 25 MEDs so far projected to exceed).
- Will cost almost $900M to repair the damage done by hurricanes Florence and Michael in Duke territories across the SE (of which $540M is attributed to Florence in the Carolinas).
- Number of billion-dollar disaster events in the U.S. have steadily increased in the past 30 years (3 in 1980 to 16 in 2017).
- Trend projects over $150M per year by 2023, and over $200M by 2028. [Source: DE data]

Reliability in General (non-MED)

- SC System Average Interruption Duration Index (SAIDI) projected to raise from 205-215 in 2019, to 315-325 in 2028.
- SC System Average Interruption Frequency Index (SAIFI) and momentaries also growing worse. Projected to move from 1.39-1.47 in 2019 to 1.89-1.97 in 2028.

Details

Maintaining the grid at a manageable state in the heatmap requires continued improvement over time. This means that some projects will result in “green” throughout their time of implementation while others require continued consecutive implementation of projects over time.

Decreasing Costs

- With our Grid Improvement Plan (GIP), prices will eventually decrease.
- As grid investments that help prepare the grid for storms, population growth, and DER adoption are rolled out, the associated cost savings that follow will support energy affordability.

Reliability in General (non-MED)

- SC SAIFI projected to be 39% better than BaU work by year end (YE) 2028 with implementation of proposed GIP scope of reliability
- SC SAIFI projected to be 39% better than BaU work by year end (YE) 2028 with implementation of proposed GIP scope of reliability
- SC CEMI6 % of customers impacted could be reduced by 2.8x from the business-as-usual (BaU) scenario over 10-year plan

Program Results

- Decreased outages and cost of restoration for major weather events.
- Decreased costs associated with building capacity in high growth areas.
- Serving load in congested circuits using unused capacity from neighboring circuits.

Reliability in General (non-MED) – *continued*

- Percent of CEMI6 customers impacted expected to raise from 2.7% to 5.1% by 2028, leading to increased customer dissatisfaction. [Source: DE data]
- In the Carolinas, business losses can range up to $17,000/hr as a result of a single power interruption [Source: P/F NC White Paper].

Cyber/Physical Attacks

- BaU infrastructure cannot protect as well against more complex threats. Costs to customers will increase as Duke responds to or recovers from increased attacks.
- Industrial Control Systems Cyber Emergency Response Team estimates a similar incident to the Ukrainian power grid attacks in the US would result in damages totaling between $243 billion and $1 trillion.
- Sniper attack on Pacific Gas & Electric (PG&E) transmission station caused $15M in damages and led to $100M in physical security investments.
- Cost of damage from the most extreme solar event is estimated to cost $1T to $2T. [Source: see SC Megatrend I].

Concentrated Growth

- SC population expected to grow by ~8% (2018-2026); Urban zone like Greenville/Spartanburg accounted for 64% of upstate growth with [Source: see SC Megatrend VI].
- Rapid urbanization is constraining urban circuit capacity; BaU response is to build new capacity to accommodate, however urban land needed for infrastructure expansion is even more expensive today than when system originally built.
- Additionally, congested circuits will lead to an increasingly limited ability to integrate DERs, causing customers with solar-based sustainability and decarbonization strategies to miss their renewable goals.

Key Programs

- **IVVC** - allows deferment or elimination of the need to run less efficient peaking generation, reduce the amount of expense required by spot market electricity, and reduce the amount of fuel required to generate electricity to meet demand.
- Expected to be producing benefits Duke Energy Carolinas (DEC) systemwide commensurate with the IVVC BCA.
- **SOG** – enables advanced planning for capacity constraints and two-way power flow that are more cost-effective than reactionary investment. SOG alone is expected to produce additional customer benefit from reduced customer interruptions (e.g., outages and momentaries) over its lifetime (pursuant to SOG BCA).
- **Distribution Automation/Transmission Intelligence** – allows for significant reduction in number of outages to lessen disruption to businesses and their employees
- **Targeted Undergrounding/T&D Hardening and Resiliency** – allows for a more resilient/reliable grid by targeting improvements to only those portions of the system that create cost- justified benefits for customers
- **Long Duration Interruption/High Impact Sites** – improves reliability for high-impact customers using technologies and approaches that yield cost- justified benefits for customers
- **Energy Storage** – improves reliability and expands customer options and control in applications that offer cost-justified benefits for customers

	Increased DER Penetration • Higher adoption of residential DER creates localized oversupply, specifically during shoulder seasons (spring and fall) when load is low but solar production is high, leading to high voltage issues and back feeding of supply upstream to substations and the transmission systems. • Substations and transmission systems area not designed nor prepared for increased back fed DER supply and the associated over voltage conditions. \ Nationally, DER expected to grow 8 times faster than net new centralized generation in the next 10 years. • DEC SC customer-scale solar programs reached 40 MW cap in 13 months (10/2015-11/2016); DEP has reached ~60% of its 26MW cap [Source: see SC Megatrend II].	

	Under Business as Usual	With Grid Improvement Plan
Reliability & Resiliency	Gradual Yellow to Red **2018** **2028** **2018-2020 (yellow)**: Customers, especially rural, already experiencing lower reliability. SC 2017 System Average Interruption Duration Index (SAIDI) at 320 (across DEP/DEC), System Average Interruption Frequency Index (SAIFI) of 1.9, approx. 5.1% customer experience CEMI6. 2018 has seen 25 MEDs thus far (5-year trailing average of 15/year at $6M+/MED to repair/recover). **2021-2024 (worsening to red):** Aging infrastructure replacement does not adequately address reliability issues. New infrastructure investments concentrated in high growth areas and rural areas experience disproportionate impact of worsening reliability trend. By 2023, SAIDI and SAIFI both projected to be worse than 12-year trailing average (73% and 27% worse respectively). MEDs average 25/year expected to be new norm by 2023/2024 based on trend, estimated at over $150M/year in repair recovery. **2025-2028 (red):** Trends above lead to worsening reliability. This includes reliability issues due to growing DER penetration (distributed PV and EVs) and increasing threat of cyber and physical attacks. SAIDI projected to grow to 320+ level, SAIFI to 1.95+ and CEMI6 to reach 5.1% of customers. MED trend indicates $200M+/year in response/repairs. **<u>Details</u>** **Current Issues** • 2018 is yellow because some customers (mainly rural areas) are experiencing low reliability and resiliency but do not represent the majority of customers (concentrated growth in cities currently have greater reliability	Yellow to Lime Green **2018** **2028** **2021-2025 (gradually transition to lime green):** By 2023, these investments improve the BaU scenario (SAIFI projected to be 4% better and SAIDI will see only a 26% decline than 12-year trailing average (verses the 27% and 73% declines projected, respectively, without GIP). Also, IVVC and ES starting to provide improved ability to better integrate DER. **2026-2027 (green):** The investments continue to work together to enable growing DER (distributed PV and EV) penetration without increased reliability and PQ problems (e.g., SOG allows an additional distributed solar capacity to be reliably integrated -- pursuant to SOG BCA). Physical and Cyber security investments help reduce the occurrence of continually more complex attacks on the infrastructure. **<u>Details</u>** **Summary Notes**: Grid Improvement Plan – If we implement our proposed GIP scope of reliability work by year end (YE) 2028: • SAIFI is projected to be 39% better than BaU projected value over same timeframe • SAIDI is projected to be 45% better than BaU projected value over same timeframe Key programs that help this trend include: • **SOG** – expands circuit capacity and connectivity and deploys automation so electricity can quickly (< 1 min) and automatically be rerouted and delivered to customers when a line fault occurs • **Distribution Automation** – projects automate circuit switching to reduce the impacts of faults or equipment failures on the line by quickly isolating issues; Programs like the fuse replacement

	Reliability in General (non-MED) • SC System Average Interruption Duration Index (SAIDI) projected to raise from 205-215 in 2019, to 315-325 in 2028. • SC System Average Interruption Frequency Index (SAIFI) and momentaries also growing worse. Projected to move from 1.39-1.47 in 2019 to 1.89-1.97 in 2028. • Percent of CEMI6 customers impacted expected to raise from 2.7% to 5.1% by 2028, leading to increased customer dissatisfaction. **MEDs – Major Event Days—**reliability and cost drivers • The number of annual MEDs is increasing at 4.6% per year over the past 10 years. Trend shows 2.5x more MED-days in 2018 than 2008. • Number of MED outages up from 5 years ago; average restore cost per outage (5-year average) is $5500 per outage; Nearly 100k MED outages across the Carolinas in past 5 years (2013 to 2018) for average cost of ~ $100M per year for MED restoration. • National Weather Service has cited an 80% increase in the number of severe weather events impacting the U.S. from 2000 to 2016 **Aging infrastructure—**Urban/Rural divide • Like-for-like replacement of technology will not lower costs or improve reliability • BaU will continue to exacerbate differences between higher growth and metropolitan areas (Greenville and Spartanburg counties expected to grow roughly 25% to 30% through 2030) vs. rural and lower growth areas, as opportunities for grid upgrades are minimal in these lower growth areas. • Grid will increasingly have less ability to integrate DERs **Cyberattacks—**Global trend shows these are getting more complex and starting to get thru current defenses.	program significantly reduces the number of power blinks (momentaries) customers would experience. • **TUG** – Certain customers will see significant improvements in reliability as their service is undergrounded; storm response resources can be more effectively deployed to other customers to restore power faster following major weather events • **T&D H&R** – significantly reduce the frequency and impacts of major weather events on the system • **Cyber & Physical Security—** projects help reduce the risk of system impacts from attacks • **IVVC DEC** – (peak shaving) can reduce the risk of blackouts or rolling brownouts due to supply constraints • **Transmission Intelligence** – automates T-circuit switching to reduce the impacts of faults or equipment failures on the line by quickly isolating issues • **Energy Storage**— can support reliability or PQ issues • **EV Charging Pilot** – supports EV studies for identifying and proactively addressing EV-driven reliability or PQ issues **<u>Distributed Solar Forecast</u>** [source: DE PF2.0 WS3 Business Case Analysis NC inputs—10-29-18)] Example of how SOG investment helps accommodate levels forecast: • **SOG enablement**: for distributed PV, SOG investment enables additional capacity *on average* starting in 2027 (based on the projected net energy metered photovoltaic (NEM PV) market growth. • However, the SOG investment is very likely to help enable distributed PV in some densely deployed areas starting as early as 2021 initial deployment, growing through 2023 when initial GIP deployment is finalized. **<u>Electric Vehicle Forecast</u>** [source: EV Cost-Benefit Analysis, MJB&A, June 2018; DE PF2.0 WS3 BCA NC inputs 10-29-18)]

	Distributed Solar Forecast Distributed solar capacity in SC projected to more than double from under 401MW to over 900MW (2017 to 2023), [source: SEIA SC Factsheet] By around **2021**, green starts to turn yellow. • Evidence: by 2025, rooftop solar penetration capacity doubles over 2017 levels (from roughly 400 MW residential to over 900MW). • For areas of the system with higher density PV than average, this will start to create integration costs and challenges that must be addressed. • Support: If we do not start to add **voltage management, automation, visibility** and 2-way power flow, we will see impacts to service, and we need to keep in mind the ramp up time to secure approval and implement these types of programs. Around **2025**, yellow starts to turn red because rooftop solar is starting to become cost effective at scale; PV density continues to grow in some areas requiring additional costs to integrate. • Looking out over 10-year time horizon, megatrend data tells us the cost of solar will continue to decline and will reach a tipping point where we will see much deeper rooftop penetration across the footprint that will start to burden the system. During **2027**, residential rooftop solar reaches **price parity with retail price of electricity** and when this happens, it happens everywhere at once (source: Bloomberg New Energy Finance, Lithium-ion Battery Costs and Market. 2017). **Electric Vehicle Forecast** [source: EV Cost-Benefit Analysis, MJB&A, June 2018] Penetration of PEV light duty vehicles by 2030: • 7K today, • 5% (470K by 2030) - baseline • 25% (2.4m by 2030)- aggressive intervention	Example of how SOG/IVVC will help accommodate EVs at greater levels. • **SOG** and **IVVC** will also make it easier to add EV charging infrastructure in key areas where it is needed, starting in 2021. • It will also provide greater flexibility and option value towards integrating higher penetrations of EVs under aggressive EV public policy scenarios. **BTM Battery Storage** Utility Scale batteries can play a significant role in areas such as duck curve mitigation and potentially support for voltage and frequency management, etc.

"The largest contributor to incremental purchase costs for PEVs compared to gasoline vehicles is the cost of batteries. Battery costs for light-duty plug-in vehicles have fallen from over $1,000/kWh to less than $300/kWh in the last six years; many analysts and auto companies project that battery prices will continue to fall – to **below $110/kWh by 2025**, and **below $75/kWh by 2030**. [3] Based on these battery cost projections, this analysis <u>projects that the average annual cost of owning a PEV in North Carolina</u> will fall below the average cost of owning a gasoline vehicle **by 2035**, even without government purchase subsidies." (p.10)

<u>BTM Battery Storage</u>

BTM batteries are not expected to play a major role in the need for grid investment in the near term.

[source: Navigant – Duke RE Price Forecast, Sept 2018]
Residential scale, distributed battery costs are expected to continue falling significantly during the next 10 years. For example, a 5kW/13kWh system costs average $10K in 2018 but will fall to approximately $6k by 2027.

	Under Business as Usual	**With Grid Improvement Plan**
Ability to meet customer expectations	Green to Yellow gradually to Red  **2018-2020 (green to lime green**): Declining reliability due to aging infrastructure, increasing storm activity, and concern over electricity pricing are starting to impact customer satisfaction: JD Power Residential scores for DE-NC in 2nd/3rd Quartile of like utilities 2015-2018, but Commercial customer score below that of peer utilities in South Region with recent 672/678 DEC/DEP scores vs 731 for top utility. Rooftop solar net metering program, reaches its 2% cap in DEC-SC and DEP-SC in 2018 and 2020, respectively. **2021-2024 (yellow):** Interest in rooftop solar expected to triple from current levels by 2021 while reliability metrics continue to worsen leading to increasing customer dissatisfaction. MED events (expected to average an additional 3 MEDs/year by 2023) further hurting reliability and putting upward pressure on cost of service. **2025-2027 (moving to red):** By 2025 DER integration limitations become widespread. In 2027 residential solar reaches price parity with retail electricity costs, and solar installed capacity expected to increase 9% per year from 2018-2017). [Source: SC Megatrend II] Inability to provide charging infrastructure for EVs in some areas becomes a problem (EVs reach 3-4% of light-duty vehicle stock). Reliability has continued to decline (by 2028, SAIDI reaching 315-325, SAIFI grows to 1.9 in some areas, and CEMI6 growing by 66% to affect over 5% of customers). [Source: DE SME] Increasing costs to pay for MED and non-MED recovery activities and customers.	Gradual Green to Yellow back to Green  **2018-2020 (green to lime green):** Initial reliability investments in Targeted Undergrounding (TUG), Distribution Automation (DA), and Self-Optimizing Grid (SOG) projects begin to improve reliability for targeted areas and slowly begin to impact overall customer satisfaction results (VVC, Power Electronics, Cyber Security deployed, but significant effects not yet seen on large scale. **2021-2025 (lime-green to yellow):** Continued reliability investments in TUG, DA, SOG are required to continue improved reliability trend in targeted neighborhoods complete by 2025). By end of this period IVVC, Power Electronics, and DER dispatching tool help ease integration of DERs. **2026-2028 (yellow to green):** effects of investments noted above continue to accumulate. TUG, DA, SOG continue to reduce impacts of non-MED reliability issues as well as the most significant costs and impacts of increased MED occurrence. CEMI6 % of customers impacted expected to be reduced by 2.8x from the BaU scenario. Distributed PV growth is accommodated more easily, and in SOG areas is completely accommodated w/o extra investment. Cyber Security helps prevent infrastructure attacks, reducing disruption and the corresponding expenses.

Details

Overall customer wants: [Source: SECC]

- Low and reasonable energy prices; save money by using energy more efficiently
- Reliability: prevent and reduce length of outages
- Reducing greenhouse gas emissions; make it easier to connect renewables and provide cleaner central generation
- Greater choice and options for energy technologies and pricing.
- Generational change: millennials and up & coming generation favor cleaner energy and more choice much more strongly than older generations

JD Power Measurements –Overall customer Sat

Elements scored: Power Quality and Reliability, Price, Billing & Payment, Communications, Corp. Citizenship, Customer service.

- Key declines were observed in the areas of billing and payment, which remained a significant area of underperformance in 2018.
- Commercial Scores DEC-SC and DEP-SC in 2018 were lower than peers in the south region large utilities. Scores were 764 and 765 respectively. A top score of 803 was achieved by Georgia Power

MEDs – Major Event Days—reliability and cost drivers

- Trending upwards for past 10 years for the Carolinas. Trend shows 6 more MEDs/year in 2018 than 2008 (from trend of 13 to over 19).
- MEDs are disruptive to reliability and expensive to respond to and address problems created.
- Each MED costs $millions, raising cost of service
- National Weather Service has cited an 80% increase in the number of severe weather events impacting the U.S. from 2000 to 2016

Details

Reliability in General (non-MED)

- SC SAIFI projected to be 39% better than BaU work by year end (YE) 2028 with implementation of proposed GIP scope of reliability
- SC SAIDI projected to be 45% better than BaU work by year end (YE) 2028 with implementation of proposed GIP scope of reliability
- SC CEMI6 % of customers impacted could be reduced by 2.8x from the business-as-usual (BaU) scenario over 10-year plan

Key Programs

- **IVVC** in DEC and **DSDR peak shaving to CVR** in DEP – allow more efficient use of customer electricity by running at lower voltage still within ANSI standards—leading to customer savings
- **SOG** – provides more reliable and efficient use of the grid.
- **TUG** – reduces many weather and vegetation related faults to improve reliability in targeted areas. Targeting areas of most need first.
- **Energy Storage** – supports two-way power flow by absorbing excess generation from solar for later use, for additional DER integration.
- **Distribution Automation** – supports dynamic and growing distribution system loads in a more sustainable way while minimizing power quality issues that often accompany a large-scale transition to solar power.
- **Power Electronics** – More DER integration.
- **Cyber Security—**allows DERs to be securely connected, and thus allows better visibility (e.g., smart inverter connections.)
- **T&D Communications**—enables more grid visibility for DER monitoring and integration.
- **ISOP—**enables stacked value of DER resources to be integrated more readily into grid planning. Helps, enables more integration at lower cost overall.
- **DER Dispatch Tool** – DER manageability (system visibility & load control).

	Reliability in General (non-MED) • SC System Average Interruption Duration Index (SAIDI) projected to raise from 205-215 in 2019, to 315-325 in 2028. • SC System Average Interruption Frequency Index (SAIFI) and momentaries also growing worse. Projected to move from 1.39-1.47 in 2019 to 1.89-1.97 in 2028. • CEMI6 % of customers impacted expected to raise from under 3% to over 4.5% by 2028, leading to increased customer dissatisfaction. [Source: DE data] **Aging infrastructure—**Urban/Rural divide • Like-for-like replacement of technology will not lower costs or improve reliability • BaU will continue to exacerbate differences between higher growth and metropolitan areas (e.g., Greenville county expected to grow 32% through 2028) vs. rural and lower growth areas, as opportunities for grid upgrades are minimal in these lower growth areas. • Grid will increasingly have less ability to integrate DERs **Ability to Access Net Metered PV**—satisfaction driver • The growing adoption of private solar has led to an increasingly complex circuit impact studies, longer interconnection application queues and potentially longer queue times for DER interconnection applicants. As DER hosting capacity becomes more limited and circuits overly congested, indefinite moratoria on interconnections to some circuits may be required. **Increased Customer Reliance on Electricity—**businesses and consumers growing more reliant on the grid. • More automation and electrical appliances in homes and businesses • Electrification and fuel switching for various applications is increasing (heat-pumps, water heat, gas to electric) • Nationally, electric vehicle use is growing: EVs are expected to make up 3-4% of SC light-duty vehicle stock by 2028.	• **EV Charging** – direct enablement of DER and meeting customer desires for more product choice and options.

	Under Business as Usual	With Grid Improvement Plan

Ability to manage and integrate DER	Gradual Green to Red
	2018 2028
	
	2018-2020 (green—light green): Rooftop solar and EV penetration remain low enough on *average* in the next 2-4 years that significant costs and issues should largely be avoidable.
	
	2021-2024 (turning to yellow): Rooftop solar doubles from current levels by 2021, and areas of more dense rooftop solar are likely to create localized integration costs and bottlenecks.
	
	2025-2028 (yellow-turning to red): by 2027, residential solar reaches price parity with retail electricity costs, and distributed solar penetration has doubled from 2017 levels by 2025 (from roughly 400 MW to over 900MW). Capacity for adding more distributed solar to the system *on average* is limited, and some areas of high density demand have moratoria on new applications. EV penetration levels start to reach 3-4% of light-duty vehicle stock, also creating localized charging challenges.
	
	__**Details**__
	2018 is green because rooftop solar has not yet reached the density level (on average) where upgrades are required.
	• Even though green today, there may be some pockets that are red.
	    ○ Quantitative assumptions of PV look at an average but there will be certain substations that will have excess solar sooner. This explains the yellow period between 2019 and 2025.
	    ○ EV penetration under baseline assumptions is expected to continue to be low for the next several years, so is not contributing to the yellow.
	• Starting in 2025 the yellow starts to shift to red on a more system-wide average
	    ○ The deployment of distributed solar has more than doubled over 2018 levels by 2021. Residential solar energy costs reach price parity by about 2027. And, distributed solar capacity has more
		Green to Lime Green
		2018 2028
		
		2018-2020 (green):
		IVVC, SOG, power electronics and DA investments lay the groundwork for faster, less expensive DER integration in key locations.
		
		2021-2024 (turning to lime green):
		2021-2024 transitions to a lighter green because although some circuits will be updated to "green", there are more that are not updated by the time adoption accelerates projected for mid-2020s.
		
		2025-2028 (lime green):
		DER dispatch tool, ISOP, and EV Charging learnings allow better optimization of DER on the system. SOG alone provides additional MW of distributed PV capabilities in the deployed areas (as described in SOG business case analysis). However, many areas still not conditioned to support higher DER densities and so color remains lime-green.
		
		__**Details**__
		2021-2024 transitions to a lighter green because although some circuits will be updated to "green", there are additional that will not have been updated by the time adoption accelerates projected for mid-2020s.
		.
		• In 2028 bright green represents isolated pockets of issues.
		Key programs that help this trend include:
		• **IVVC DEC** – allows the distribution system to optimize voltage and reactive power needs. Provides more visibility and allows more DER integration.
		• **DSDR peak shaving to CVR in DEP** – course voltage/Var management allows for more hosting capacity for DERs/PV in SOG areas, more ability to handle EVs, etc.

than doubled (from 2017) by 2025, leading to widespread costs and challenges with PV integration.
  - It can take up to 2 years to schedule an outage to upgrade substation
  - EV penetration under baseline scenario reaches 3-4% by 2028, starting to create challenges in some areas.

Distributed Solar Forecast

Distributed solar capacity in SC projected to more than double from under 401MW to over 900MW (2017 to 2023), [source: SEIA SC Factsheet]

By around **2021**, green starts to turn yellow.

- Evidence: by 2021, rooftop solar penetration capacity doubles over 2018 levels (from under 60MW residential to over 130).
- For areas of the system with higher density PV than average, this will start to create integration costs and challenges that must be addressed.
- Support: If we do not start to add **voltage management, automation, visibility** and 2-way power flow, we will see impacts to service, keeping in mind the ramp up time to secure approval and implement these types of programs.

Around **2025**, yellow starts to turn red because rooftop solar is starting to become cost effective at scale; PV density continues to grow in some areas requiring additional costs to integrate.

- Looking out over 10-year time horizon, megatrend data tells us the cost of solar will continue to decline and will reach a tipping point where we will see much deeper rooftop penetration across the footprint that will start to burden the system.

During **2027**, residential rooftop solar reaches **price parity with retail price of electricity** and when this happens, it happens everywhere at once.

Electric Vehicle Forecast

Penetration of PEV light duty vehicles by 2030:

- 7K today,
- 5% (470K by 2030) - baseline
- 25% (2.4m by 2030)- aggressive intervention

- **SOG** – capacity projects focus on expanding substation and distribution line capacity to allow for two-way power flow. More capacity for distributed solar and EVs.
- **Energy Storage** – supports two-way power flow by absorbing excess generation from solar for later use.
- **Distribution Automation** – supports dynamic and growing distribution system loads in a more sustainable way while minimizing power quality issues that often accompany a large-scale transition to solar power.
- **Power Electronics** – protective device technology to detect and respond to rapid voltage and power fluctuations of non-dispatchable resources such as solar.
- **Cyber Security—**allows DERs to be more securely connected, and thus allows better visibility (e.g., smart inverter connections.)
- **T&D Communications**—enables more grid visibility for DER monitoring and integration.
- **ISOP—**enables stacked value of DER resources to be integrated more readily into grid planning. Helps enables more integration at lower cost overall.
- **DER Dispatch Tool** – DER manageability (system visibility & load control).
- **EV Charging** – direct enablement of DER.

Distributed Solar Forecast

[source: DE PF2.0 WS3 BCA NC inputs—10-29-18)]
See details at left for forecast.

Example of how SOG investment helps accommodate levels forecast:

- **SOG** enablement: for distributed PV, SOG investment enables additional capacity *on average* starting in 2027 based on the projected NEM PV market growth (pursuant to SOG BCA)
- However, the **SOG** investment is very likely to help enable distributed PV in some densely deployed areas starting as early as 2021 initial deployment, growing through 2023 when initial P/F2.0 deployment is finalized.

	"The largest contributor to incremental purchase costs for PEVs compared to gasoline vehicles is the cost of batteries. Battery costs for light-duty plug-in vehicles have fallen from over $1,000/kWh to less than $300/kWh in the last six years; many analysts and auto companies project that battery prices will continue to fall – to **below $110/kWh by 2025**, and **below $75/kWh by 2030**. [source: EV Cost-Benefit Analysis, MJB&A, June 2018] Based on these battery cost projections, this analysis <u>projects that the average annual cost of owning a PEV in South</u> Carolina will fall below the average cost of owning a gasoline vehicle **by 2035**, even without government purchase subsidies. [Source: SC Megatrends II] **<u>BTM Battery Storage</u>** Behind the meter (BTM) or privately-owned batteries are not expected to play a major role in the need for grid investment in the near term. Residential scale, distributed battery costs are expected to continue falling significantly during the next 10 years. For example, a 5kW/13kWh system costs average $10K in 2018 but will fall to approximately $6k by 2027. [source: Navigant – Duke Renewable Energy Price Forecast, Sept 2018]	**<u>Electric Vehicle Forecast</u>** Example of how SOG/IVVC will help accommodate EVs at greater levels. • **SOG** and **IVVC** will also make it easier to add EV charging infrastructure in key areas where it is needed, starting in 2021.It will also provide greater flexibility and option value towards integrating higher penetrations of EVs under aggressive EV public policy scenarios. [source: EV Cost-Benefit Analysis, MJB&A, June 2018] **<u>BTM Battery Storage</u>** Utility-scale batteries can play significant grid support roles • **Duck curve mitigation** - mitigating the "duck curve" effect by storing the oversupply of energy generated mid-day when solar production is high and baseload generation is running, and then discharging to alleviate the quick ramp up of generation required as sunsets and solar production ebbs coincident with evening peak load • **Frequency support** – supporting a circuit's need for frequency regulation, often done by ramping of generation assets up or down which typically takes minutes; batteries have the capability to do this in milliseconds thereby improving system stability • **Voltage support** – supporting circuits by charging or discharging to reduce high or low voltage conditions, or voltage and frequency management, etc.

	Under Business as Usual	With Grid Improvement Plan
Economic Competitiveness	Gradual Green to Yellow 2018 2028 **2018-2022 (green)**: SC has some thriving cities with progressive plans (e.g,. smart cities in Greenville and Columbia). Is highly attractive to millennials (Columbia #2 city in the country for net migration by millennials) who will build the next generation economy and are important factor in attracting jobs. [source: The State] **2023-2025 (gradual transition to yellow):** Reliability issues and inability to efficiently accommodate greater DER demands start to impact businesses view of state. Increasing costs of doing business in key urban/suburban areas put drag on competitiveness. The effects lag 2 to 4 years behind as businesses assess the situation. **2026-2028 (yellow):** Uncertainty of businesses meeting their environmental commitments due to perceived “unfriendliness” to DERs (moratoria in certain areas), declining reliability (SAIDI above 320) and increased cost of doing business in key locations start to reduce overall economic competitiveness of SC. **<u>Details</u>** **Electricity Rates –** attractive rates • Rates are currently a lower than national average in SC • SC in lower half of US rates [Source: EIA] **Opportunities to Incorporate Renewables** • SC ranked 8th the nation for highest solar generation capacity in 2017 and is home to 81 solar companies total (including 14 manufacturers) [source: SEIA SC Fact sheet]	Green Across 2018 2028 **2018-2022 (green)**: IVVC, SOG, Power Electronics provide foundation for faster, less expensive DER integration. TUG avoids outages in targeted areas and T&D Automation along with SOG investments provide mechanism to get the lights back on quicker than previously possible. **2023-2025 (lime):** Ability to interconnect DER effectively makes SC more attractive for businesses with renewable energy commitments (48% of Fortune 500 companies have sustainability and renewable energy commitments). Reduced outage frequency and duration become key selling points for competitiveness. **2026-2028 (green):** Ease of DER integration and EV support (with additional DER integration capacity enabled by SOG as documented in the SOG BCA) help meet customer needs. Reliable service makes SC highly attractive for new business and business growth. Physical and cyber security investments help reduce threat and impact of infrastructure attacks **<u>Details</u>** **Integration of DER** • Ability to interconnect DER effectively makes SC more attractive for businesses with renewable energy mandates • 48% of Fortune 500 companies have sustainability and renewable energy commitments • Businesses want to purchase renewable resources located near their facilities

- Large corporations/industries have the desire to integrate renewables
- 48% of Fortune 500 companies have sustainability and renewable energy commitments, including leading SC corporations like BMW, Michelin, Milliken, Walmart, Fujifilm, Ingersoll Rand, Owen Corning, Sealed Air Corp and VF Corp [source: SC Megatrend II]

Reliability in General (non-MED)

- Inability to provide uninterrupted power supply could lead to detraction of businesses in the area
- SC System Average Interruption Duration Index (SAIDI) projected to raise from 205-215 in 2019, to 315-325 in 2028.
- SC System Average Interruption Frequency Index (SAIFI) and momentaries also growing worse. Projected to move from 1.39-1.47 in 2019 to 1.89-1.97 in 2028.
- Percent of CEMI6 customers impacted expected to raise from 2.7% to 5.1% by 2028, leading to increased customer dissatisfaction. [Source: DE data]
- Business can have losses of $17,000/hr as a result of a single power interruption [Source: P/F NC White Paper]

Smart Cities and Infrastructure

- Population in urban areas is growing
- Success of cities essential for economic growth and sustainability
- SC cities carrying out smart city initiatives (i.e. Greenville SC Smart City Challenge) [Source: US DOT]

Impact on Industrial Customers

- Impact of BaU different from residential/commercial customers as industrial customers can experience highly impactful losses with interrupted power in certain industries.
- Poor reliability can affect suppliers, which in turn also affects industrial customers

Smart Cities

- Smart city goals established in Greenville and Columbia
- Greenville SC Smart City Challenge's vision is dependent on electric vehicles, smart grid and roadway electrification [Source: US DOT]
- City of Columbia Smart City Initiative vision is dependent on electric vehicles, smart grid and roadway electrification [Source: City of Columbia]
-

<u>Key Programs</u>

SOG - offers greater grid resiliency and reliability for SC businesses by enabling multiple energy supply options and automated re-routing of power when a fault occurs to prevent outages and quickly restore service when power outage occurs; SOG also creates more circuit capacity able to manage two-way power flow, creating the ability to better support larger customers with private onsite solar.

	Under Business as Usual	**With Grid Improvement Plan**

Geographic and demographic disparity	Gradual Dark Yellow to Red
	
	
	2018-2020 (lime green):
	Disparity is noticeable and is becoming a problem. In rural areas, reliability is lower and costs to serve higher on a per customer basis. Many more customers served by longer, single radial line with no alternate supply ties.
	• Reliability stats based on idea that co-ops are generally suppliers to rural homes. It follows that:
	  ○ IOU customers averaged slightly more than three hours without electric service while Co-op customers averaged nearly five hours without power due to more powerline miles and trees per customer [Source: EIA data on IOU vs. Muni vs. Co-op].
	• Costs to serve rural areas higher that urban areas
	  ○ Due to the lower densities of the population **spread over wider areas**, the cost of delivering energy to rural households is on average higher than for their urban counterparts [source: NRDC]
	  ○ Although costs per mile for new construction of transmission, distribution, and converting from overhead to underground lines are generally higher in urban/suburban, overall costs are higher in rural areas due to more powerline miles [Source: EEI Section 6 on undergrounding costs by geography].
	
	2021-2024 (turning yellow):
	Reliability in rural areas continues to decline. Limited opportunity to replace aging infrastructure with little/no load growth driving infrastructure investments. Spartanburg and Greenville experiencing 3% to 5% annual load growth, providing need for infrastructure upgrades.
		Gradual Dark Yellow to Lime Green
		
		
		2018-2020 (lime green):
		SOG, DA lay the foundation to mitigate negative reliability trends in targeted rural areas. DA uses reclosers to reduce outages, and TA allows more efficient targeting of problem sources in rural areas. LDI/HIS targets specific rural areas for reliability improvement.
		
		2021-2024 (yellow slowly moving to lime green):
		Non-wires alternatives (solar + storage) starts to improve reliability in rural areas as DER grows. Business start to take notice of improved reliability in these rural areas.
		
		2025-2028 (gradually turning lime green):
		Despite megatrend of people, wealth and jobs concentrating in certain areas, benefits of improved electric service in rural areas start to pay off as businesses locate here due in part to improved electric service reliability along with lower costs. Case study example illustrates: large refrigerated distribution business sited in NC after DE shows flexibility in addressing reliability requirements in rural target area. DE able to meet these needs as distribution automation build out was already approved in that area, and so were able to use the investment to meet new customer need. GIP will create more possibilities like this.

	[source: SC Megatrends VI] Business reluctant to locate to rural areas due to reliability concerns. Limited opportunity to accommodate increasingly cost-competitive solar in rural communities due to high upgrade/ integration n costs and system inability to manage intermittency. **2025-2028 (turning to red):** Disparity worsens, as business continue to leave some rural areas. Millennials continue to favor the growing population centers (e.g., Columbia, #2 ranked city in the country in 2016 for net migration of millennials) with more opportunity and more choices for renewable energy. [source: The State] Lack of infrastructure limits rural customers opportunity to benefit from solar which has reached price parity. **<u>Details</u>** **Population Changes:** uneven growth • Customers impacted increases over time as SC's population is projected to be nearly 6M by 2030 • Nearly all of fastest growing counties in major metro areas, with counties, with counties such as Greenville and York (greater Charlotte NC region) projected to grow by more than 25% and 30%, respectively, by 2030 [source: US Census Bureau 2016 Annual Population Estimates] • Two-thirds of SC's upstate growth projected to occur in Greenville/Spartanburg (urban areas) • Significant number of rural counties projected to lose population or grow at a slower rate than urban counties • Small businesses unlikely to move to rural areas with high outage rates • Due to lower population densities in rural areas, the cost of delivering energy/energy efficiency services is higher in these areas than in urban areas	**<u>Details</u>** **Reliability in General (non-MED)** • SC SAIFI projected to be 39% better than BaU work by year end (YE) 2028 with implementation of proposed GIP scope of reliability • SC SAIFI projected to be 39% better than BaU work by year end (YE) 2028 with implementation of proposed GIP scope of reliability • SC CEMI6 % of customers impacted could be reduced by 2.8x from the business-as-usual (BaU) scenario over 10-year plan **Investments Across the Grid** • Around 2025, NWAs and DER will provide back-up power to the rural areas • Distributed solar expected to increase 904 MW over the next 5 years [source: SEIA SC Factsheet] • Distributed storage expected to increase 25% per year in the next 10 years in North America • EV sales in SC saw compound annual growth rate of 43% (2011-2017) [source: SC workshop pre-read]; EV global market projected to increase 42% annually through 2020 [Source: Utility Dive] **Infrastructure Requirements** • New infrastructure required as population, jobs, and load in urban areas increase and become concentrated

	Overall customer wants: millennials • Generational change: millennials and up & coming generation favor cleaner energy and more choice much more strongly than older generations • Increase in millennial population in urban areas; the city of Columbia, SC saw second highest net migration of millennials (after Settle) according to 2016 US census bureau data [source: The State] **Reliability in General (non-MED)** • SC System Average Interruption Duration Index (SAIDI) projected to raise from 205-215 in 2019, to 315-325 in 2028. • SC System Average Interruption Frequency Index (SAIFI) and momentaries also growing worse. Projected to move from 1.39-1.47 in 2019 to 1.89-1.97 in 2028. • Percent of CEMI6 customers impacted expected to raise from 2.7% to 5.1% by 2028, leading to increased customer dissatisfaction. [Source: DE data] • Service in rural areas is worse than in urban areas since some of these rural areas share a single point of delivery that increases the chance of an outage for the whole area (community substation) **Aging infrastructure—**Urban/Rural divide • BaU will continue to exacerbate differences between higher growth and metropolitan areas (Spartanburg and Greenville counties growing at 3% to 5% every year) vs. rural and lower growth areas; Charlotte suburbs Fort Mill and Tega Cay experiencing ~52% and 33% growth, respectively [Source: SC Megatrend VI] **Increased Customer Reliance on Electricity—**businesses and consumers growing more reliant on the grid	<u>**Key Programs**</u> • **IVVC** in DEC and **DSDR peak shaving to CVR** in DEP – allow more efficient use of customer electricity by running at lower voltage still within ANSI standards—leading to customer savings • **Transmission System Intelligence** – transmission improvements enable more intelligent analysis of issues on the grid to support a wider array of customers • **Physical & Cyber Security** - allows customers to be better protected from disruptions and costs of attack in rural areas • **T&D Hardening and Resiliency** – allows for a more resilient and stronger grid that benefits customers in both urban and rural areas • **Long Duration Interruption/High Impact Sites –** improves reliability for rural or remote communities that are more susceptible to reliability issues

LIST OF ACRONYMS

BaU	Business-as-usual
BCA	Business case analysis
BTM	Behind the meter
CEMI	Customers Experiencing Multiple Interruptions
C&I	Commercial & Industrial
DA	Distribution automation
DEC	Duke Energy Carolinas
DEP	Duke Energy Progress
DER	Distributed energy resources
kW	Kilowatt
kWh	Kilowatt-hour
EV	Electric vehicle
IVVC	Integrated volt/VAR control
IOU	Investor owned utility
LDI/HIS	Long duration interruption/high impact site
MED	Major event day
MW	Megawatt
MWh	Megawatt-hour
NWA	Non-wires alternatives
NEM	Net energy metered
PEV	Plug-in electric vehicle
P/F	Power/Forward
PQ	Power quality
PV	Photovoltaic
RFP	Request for proposal
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SOG	Self-optimizing grid
TA	Transmission automation
TUG	Targeted undergrounding
Tx	Transmission
YE	Year end